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3.3 Dark matter

The dark-matter puzzle is one of the central challenges confronting particle physics, astrophysics, and cosmology. The measured rotation curves of galaxies, the mass distribution in clusters of galaxies as observed via gravitational lensing and other techniques, arguments concerning the formation of large-scale structure, and the measured fluctuations of the cosmological microwave background are powerful evidence for dark matter (Trimble, 1989; Ashman, 1992; Kamionkowski and Spergel, 1994; Mellier, 1999; Bennett et al., 2003; Spergel et al., 2003).

The lightest supersymmetric particle is a promising candidate for the dark matter in the universe (Weinberg, 1983), because it should be neutral, hence the name neutralino. It has a significant probability of not having decayed by annihilation during the early evolution of the universe, whereas most heavier supersymmetric particles would have decayed. Supersymmetry itself appears unavoidable in superstring theory and M-theory, which potentially unites all four fundamental forces of nature.

The U.S. Department of Energy has placed a high priority on the Large Hadron Collider (LHC) in large part because of it's promise to reveal physics beyond the standard model. It would be a major breakthrough, if the LHC could detect supersymmetry and the associated lightest stable particle.

Finding a particle and proving that it accounts for the observed cold dark matter are two different problems, though. The annihilation of neutralinos should give rise to a number of stable decay and fragmentation products, among them a broad gamma-ray continuum emission component in the GeV-to-TeV energy range. Most baryons and leptons disappear in the sea of cosmic rays and thermal particles in the universe, but the photons (and antiparticles) may be detectable above teh contributions of others sources (Bergström, 2000; Bertone et al., 2005). Starting with the particle mass and the annihilation cross-section determined by the LHC, it will be possible to make a focused search for the gamma-ray emission from the galactic halo. The LHC may not be successful in finding supersymmetry and neutralinos, though, for example because the neutralino mass may not be in the parameter range probed with the LHC. Gamma-ray studies, however, can sample a much wider range of masses than is possible with the next generation of accelerators, thus performing a dark matter search independent of LHC. A detection of the high-energy gamma-ray emission, and a determination of the halo profile in our galaxy, other galaxies and galaxy clusters would be a necessary step to complete the case for discovery and to elucidate the role of dark matter in structure formation.

Recently, de Boer et al. (2005) proposed that the well-known GeV-excess of diffuse galactic gamma rays may in fact be caused by dark-matter annihilations, thus requiring a low neutralino mass of around 60 GeV. The sky distribution of the GeV excess implies a fairly peculiar spatial distribution of dark matter in the Galaxy, and is also incompatible with the observed flux of cosmic-ray antiprotons (Bergström et al., 2006). In fact the antiproton data require a neutralino mass of a TeV or higher. (BOOST FACTOR?)

Only ground-based gamma- ray observatories, with an order of magnitude improvement in sensitivity above 100 GeV compared with HESS and VERITAS will have the sensitivity to cover a large fraction of LHC parameter space. **Does somebody have DarkSusy or so to figure out what the decay spectrum of a TeV-ish neutralino would be?**

mass measurements with gamma-ray line?

3.4 Lorentz violations

Lorentz invariance is one of the fundamental cornerstones of modern physics, so the possibility that it may not be exact deserves our strongest attention. Any observed deviations from Lorentz invariance would provide invaluable information on the physics operating at the Planck scale. It would be an important step towards formulating a quantum theory of gravity. Our understanding of fundamental physics will not be coherent, much less correct, until quantum gravity is understood. One of the difficulties in this quest is the paucity of detailed experimental data. The effects of quantum gravity might cause small violations of spacetime symmetries, violations that could be directly observed through the behaviour of particles at high energies or over large distances.

A large number of studies have been launched to probe the physics of Lorentz violations. On the theoretical side, it was found that string theory permits the spontaneous breaking of Lorentz symmetry (Kostelecký and Samuel, 1989). In recent years an extension of the standard model (SMex) has been developed as a Lorentz- and CPT-violating effective field theory (Colladay and Kostelecký, 1997, 1998) and subjected to a series of basic tests such as stability and renormalizability (Kostelecký and Lehnert, 2001; Kostelecký et al., 2002).

Whatever its role in the quest for a theory of quantum gravity, SMex contains coefficients that parametrize possible Lorentz violations and thus is a most helpful tool to experimentally derive constraints on the various models that involve Lorentz violations. In fact, many of these coefficients are tightly constrained by experiments, but quite a few are not. High-energy astrophysics, in particular gamma-ray measurements in the TeV-band, can provide further sensitive limits on a hitherto poorly constrained sector of the SMex (Altschul, 2006). TeV gamma-ray measurements can therefore be as effective, and in some sense complementary, to existing studies of spin-polarized matter (Bluhm and Kostelecký, 2000), analyses of the muon properties (Bluhm et al., 2000; Hughes et al., 2001), Doppler effect measurements (Saathoff et al., 2003; Lane, 2005), studies of matter-antimatter asymmetries (e.g. Gabrielse et al., 1999; Dehmelt et al., 1999; Phillips et al., 2001), experiments with cryogenic resonators (Müller et al., 2003; Stanwix et al., 2005), measurements of polarized light from distant galaxies (e.g. Kostelecký and Mewes, 2001), and others.

The Crab nebula emits synchrotron radiation from relativistic electrons with Lorentz factors up to about $\gamma = 10^9$, which has been previously used to place a very strong constraint on certain types of Lorentz violation based on the absence of vacuum Čerenkov radiation (Jacobson et al., 2003, 2004). The data indicate that the coefficient for a non-renormalizable Lorentz violation with a particular must be suppressed by at least seven orders of magnitude relative to simple $\mathcal{O}\left(E/M_{\mathrm{P}}\right)$ Planck-level scaling. Similar techniques can be applied to the more important renormalizable Lorentz-violating operators by using synchrotron and Inverse Compton data in conjunction for a variety of astronomical sources of TeV-band high-energy emission: pulsar-wind nebula (like the Crab), supernova remnants, and active galactic nuclei (Altschul, 2006).

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3.5 Cosmic rays

3.6 Particle acceleration and non-standard particle physics

The acceleration of relativistic charged particles is one of the main unsolved, yet fundamental, problems in modern astrophysics. It appears that efficient particle acceleration proceeds in systems with outflow phenomena, such as Active Galactic Nuclei, Gamma-ray Bursts, and supernova remnants (SNR). An understanding of particle acceleration in SNR may not only solve the more than ninety years old question of the origin of cosmic rays, it may also shed light on a possible connection between some aspects beyond the standard model of particle physics and the origin of very high-energy gamma rays and cosmic rays.

3.7 The physics of turbulence

Though observed and known for more than a century, the properties and ohysics of turbulence are still among the main unsolved, yet fundamental problems in modern physics. Astrophysical plasmas offer a unique laboratory to study the dynamical self-organization of a disturbed system with quasi-infinite Reynolds number, i.e. in the absence of viscous or collisional relaxation (Elmegreen and Scalo, 2004; Scalo and Elmegreen, 2004).

4 Science requirements for future experiments

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